



{In Archive} Re:

**Jose Torres** to: Mark Krueger

Cc: Larry Wright, Philip Dellinger, Ray Leissner

05/07/2009 03:16 PM

From: Jose Torres/R6/USEPA/US

To: "Mark Krueger" <markkrueger@wildblue.net>

Cc: Larry Wright/R6/USEPA/US@EPA, Philip Dellinger/R6/USEPA/US@EPA, Ray Leissner/R6/USEPA/US@EPA

Archive: This message is being viewed in an archive.

Thank you very much for copying us on the message below. I will pass the attached Power Point presentation along to my superiors and colleagues here in the Region 6 office. You are right in your assessment that this presentation embodies a discussion that is different from those recently made available to us, in part because, as you say, it calls attention to rock heterogeneities. Here are some of the points that I was able to grasp from this presentation:

It puts emphasis on details for in-situ solution mining process optimization, including details on fluid flow analysis, the factors affecting fluid flow patterns and on effective ore removal.

The authors acknowledge that the methodology discussed in the presentation are similar to those applied to enhanced oil recovery (EOR) operations (Slides 21 and 24), and some of the presented material can be traced back to the petroleum reservoir engineering literature, especially that relevant to secondary recovery operations. In fact, if a uranium rich solution could have at some point in time naturally flowed to the surface through producing wells (primary recovery) in a project, I am sure someone might have legitimately labeled the ISL process EUR (enhanced uranium recovery). Also in this presentation:

Slide 4 acknowledges the fact that aquifer formations hosting uranium ore could have permeabilities as high as several Darcies, suggesting that drilling through these low pressure formations may not provide opportunity for the development of a mud cake on the walls of the boreholes, while drilling operations may be susceptible to loss of circulation. You may have already discussed this event with water well drillers.

Slide 6, Slide 12 (notice the reference to "well field design") and Slide 16 put emphasis on the fact that well pattern may have an effect on the pattern of fluids flow within the aquifer.

Slides 14, 17, 18 and 19 discuss Sweep Efficiency, a measure of how effectively an injected fluid becomes in contact with (sweeps through) all of the target volume of rock within a well pattern. The more uniform the permeability is in a porous media, the greater the possibility that a radial flow pattern can be achieved, along with optimal sweep efficiencies.

Slide 9 emphasizes the need for "Sufficient characterization of rock hydraulic properties", an acknowledgement that the pattern of flow of fluids can also be greatly affected by lateral and/or vertical variations in, say, rock permeability within the geological zone of interest. Sweep efficiency refers to lateral and/or vertical sweep.

The message in Slide 19 is that permeability variations across an aquifer affect the pattern of fluid flow, whether a well is an injector or a water supply well. The authors seem to be pointing to the fact that field experience shows that if lateral changes in permeability are pronounced, the flow pattern within the area affected by a well might not be considered radial flow. If this is the case, a producing well's area of drainage, for example, would not be shaped like a circle. For the same observed water production rate, this drainage area could extend to a greater than anticipated distance from this well. It follows from the above that estimated water velocities within a non-circular drainage area might be greater, compared to those in a radial pattern of flow.

Slide 8 should probably speak of "No tailings or significant SOLID waste", considering that in the in-situ solution mining process the mix left in-situ, once the pumps shut down, could (or should) be characterized as an operational by-product (i.e.: a waste).

Thank you again for sharing this information with us, please feel free to e-mail/call me if you have questions/comments. Regards,

Jose Eduardo Torres - 6WQ-SG  
EPA, Region 6  
(214) 665-8092

Mark Krueger



**Mark Krueger** to: rabitz

04/24/2009 11:13 PM

---

From: "Mark Krueger" <markkrueger@wildblue.net>

To: <rabitz@cinci.rr.com>

---

This company gives a slightly different description of In-Situ uranium mining than what we have seen locally, particularly regarding the possibility or probability of heterogeneous fabric of the formation.



Mark Krueger Shlomo-AberraIn-situUraniumLeaching\website.ppt

# *Hydro-Geo-Chemistry and Management of *In-Situ* Uranium Leaching*

Water Management Consultants

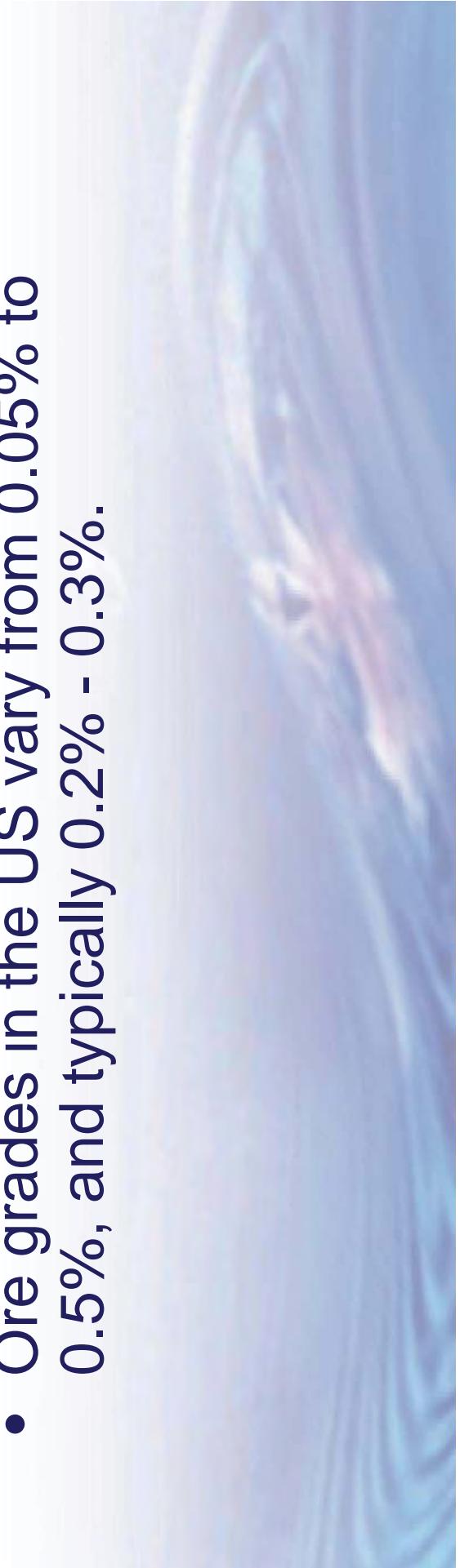
Shlomo Orr and Aberra Getahun

SME 2007

WATER  
MANAGEMENT  
CONSULTANTS

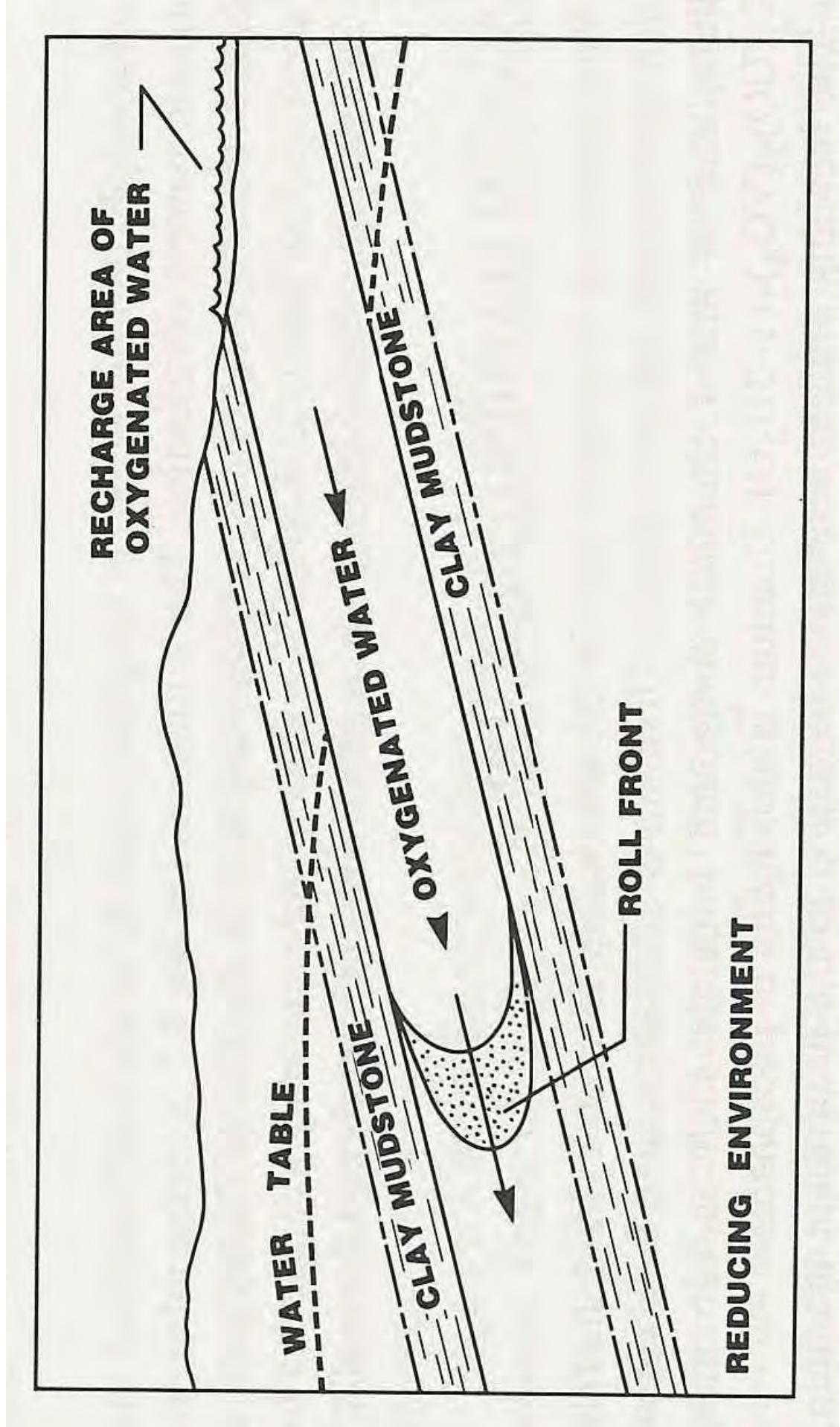
## Uranium Deposits

- Many uranium deposits occur in confined sandstone aquifers
- Such deposits develop when transported oxidized uranium solution encounters reducing conditions (oxygen depletion), and precipitates
- Ore grades in the US vary from 0.05% to 0.5%, and typically 0.2% - 0.3%.



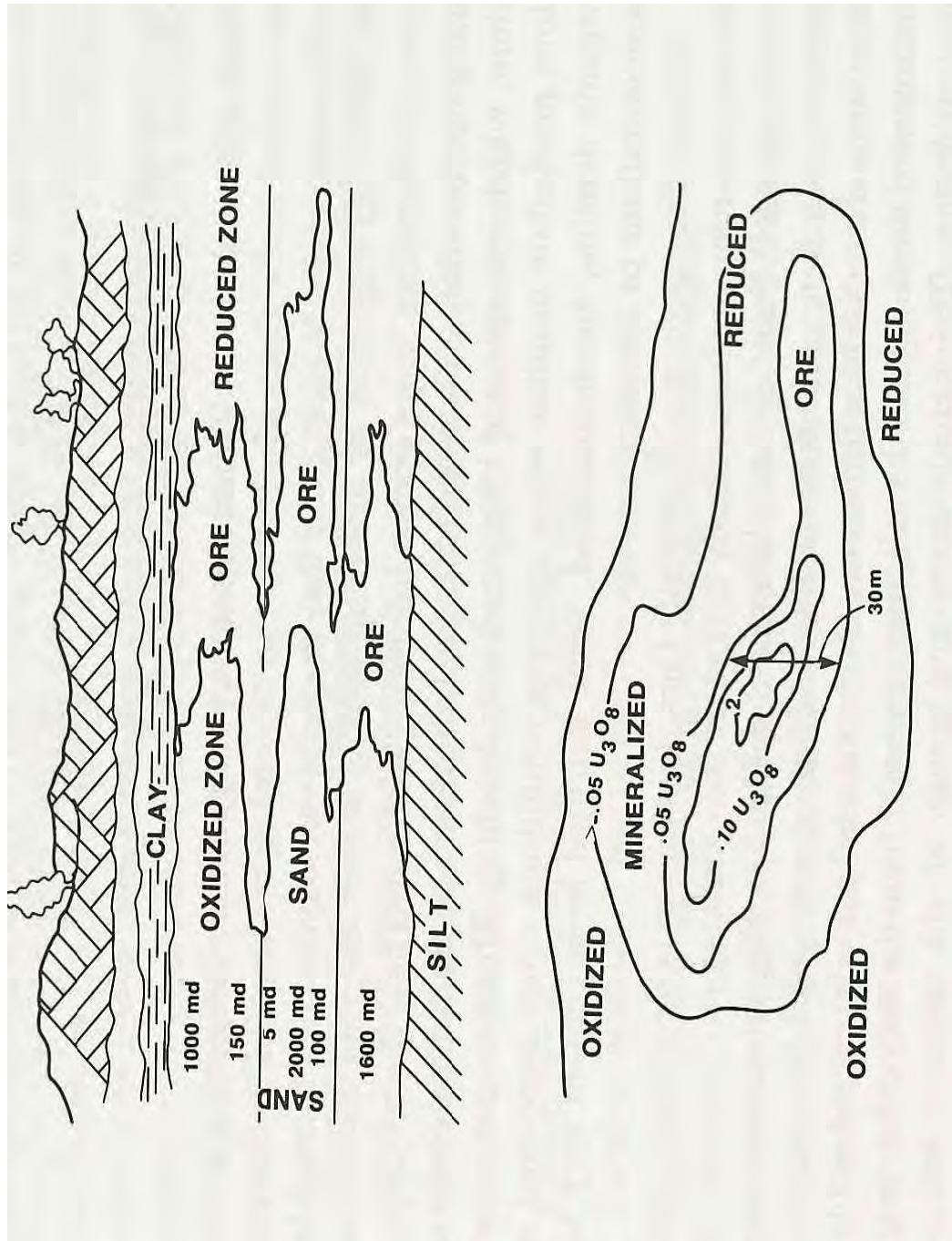
# Typical Roll Front cross section

(source: Bartlett, 1992)

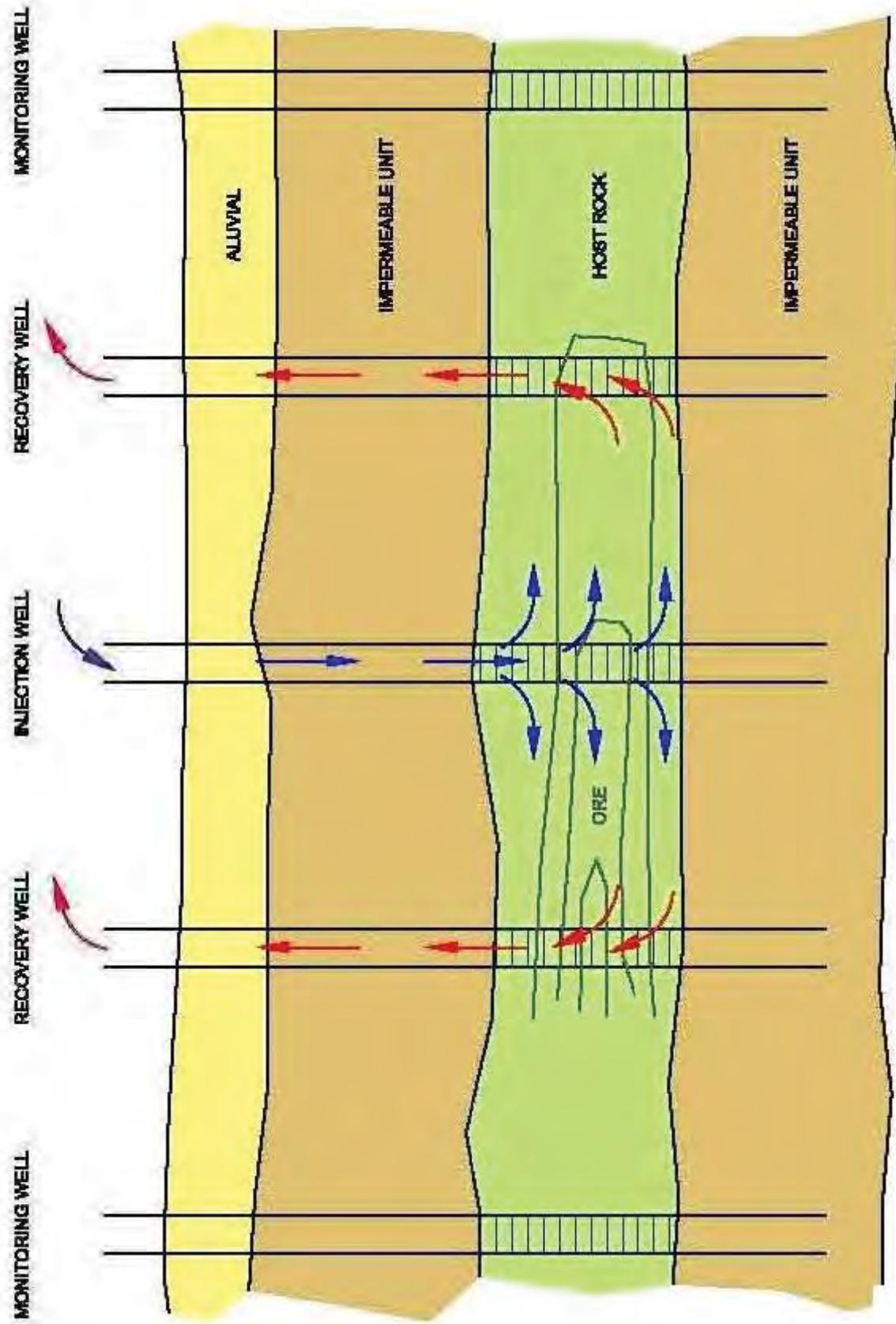


# Typical section and plan view

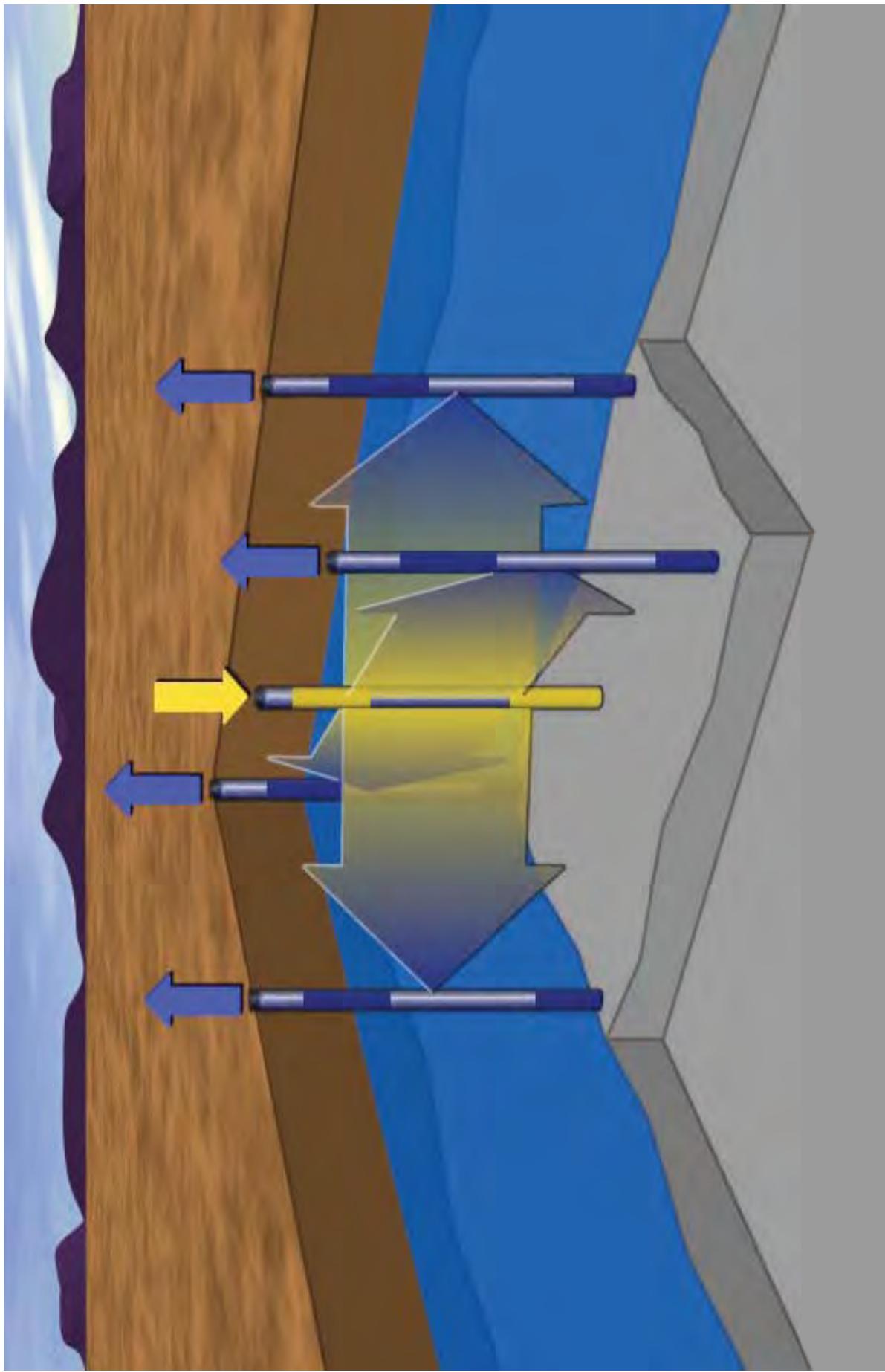
(source: Shock and Conley, 1974; Bartlett, 1992)



## IN-SITU LEACHING OF URANIUM

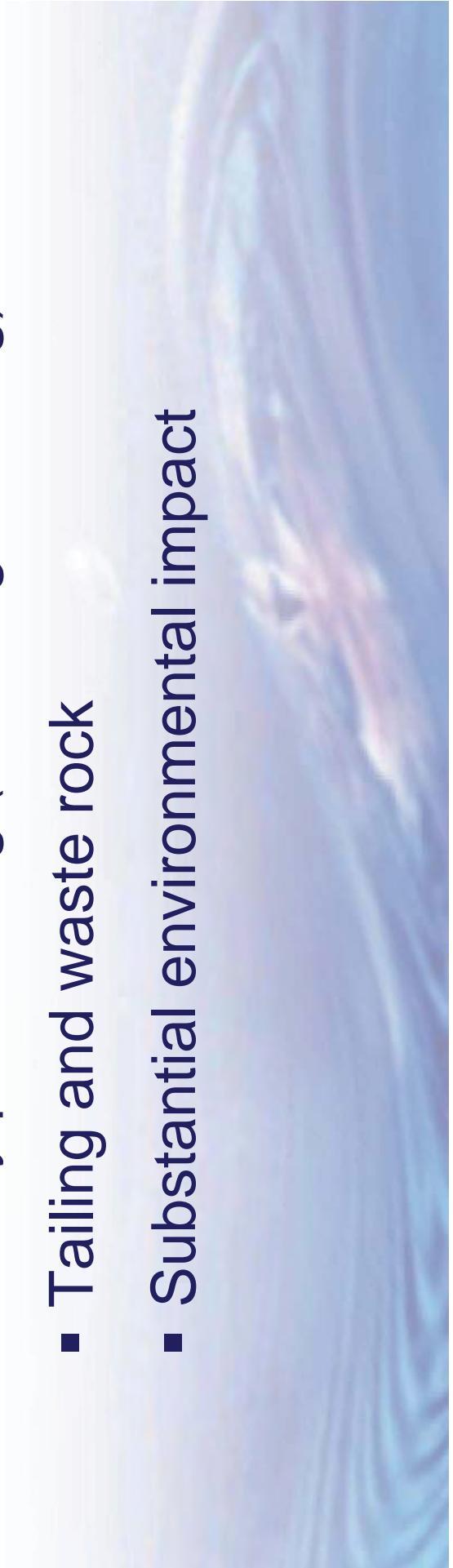


## 5-Spot unit (source: LIS)



## Conventional vs. *In-situ* mining

- Conventional mining:
  - Massive operation
  - Massive rock removal
  - Costly processing (crushing, treating)
  - Tailing and waste rock
  - Substantial environmental impact



## Conventional vs. *In-Situ* mining

- *In-situ* mining:

- Uses leach solution to recover ore
- Ore in place (no rock movement)
- Little or no surface disturbance
- No tailing or any significant waste
- Major environmental and closure advantages
- Substantial reduction in water use
- Cost-effective
- Particularly suitable for near surface oxide deposits and ores with medium to low grades towards the end of mine life cycle

## Cost Effectiveness requires

- Sufficient hydro-geochemical information
- Sufficient **characterization** of rock **hydraulic** properties, **regional groundwater conditions, mineral assemblages** – dissolution chemistry and distribution w/respect to porosity
- Sufficient **permeability** and **effective porosity**
- Sufficient **contact** of leach solution **with target ore**, and easy/sufficient solution recovery
- Favorable **general site conditions**
- Plant and reserve **economics**

## Leach Solution

- The leach solution is the “miner”
- Chemistry changes along its path
- Ideal leach solution would be:
  - Economical
  - Environmentally attractive
  - Selective (attracts only target metal)
  - Readily reactive (quick kinetics)

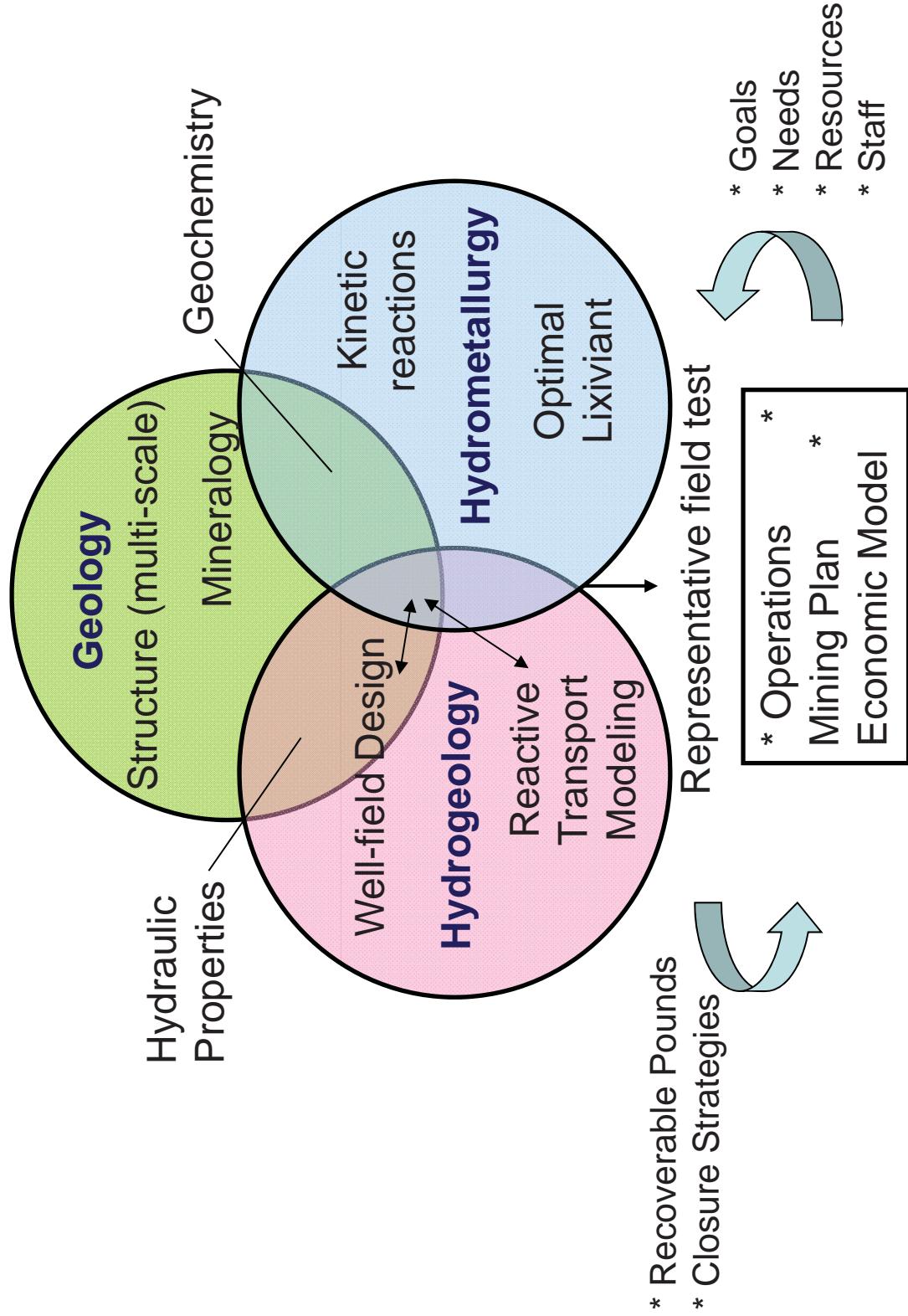
## Leach Solution

- Alkaline leaching – typically ammonium carbonate  $[(\text{NH}_4)_2\text{CO}_3]$  or sodium bicarbonate, enriched with hydrogen peroxide  $[\text{H}_2\text{O}_2]$
- Acid leaching (mostly for uranium silicate) – typically weak sulfuric acid  $[\text{H}_2\text{SO}_4]$  enriched with air sparging or ferric iron (intermediate oxidants)

## *In-Situ* Mining Technology

- Multidisciplinary approach – the intersection between, and integration of:
  - **geology** (geochemistry, mineralogy, structural),
  - **hydrogeology** (flow and transport in heterogeneous fractured formations; well field design), and
  - **hydrometallurgy** (ion exchange, elution, precipitation)
- Sensitive to hydro-geochemical parameters; therefore, requires:
  - high level of expertise in all disciplines
  - integration, and continual optimization

# *In-Situ Leaching*



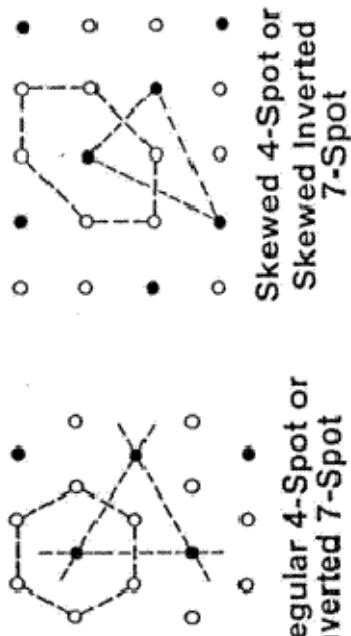
# Principles

- Understanding the hydrogeology, mineralogy of the host rock, geochemistry, and hydrometallurgy
- Optimizing the operation:
  - **Optimal lixiviant composition** (selectivity, leachability, cost, precipitate generation, and environmental effects)
  - **Maximum contact between leach solution and ore** (max sweep efficiency)
  - **Optimal solution concentrations along the flow paths**, to maximize metal extraction
- In-situ leaching optimization eliminates fatal flaws and can substantially increase revenues.

# Development Stages

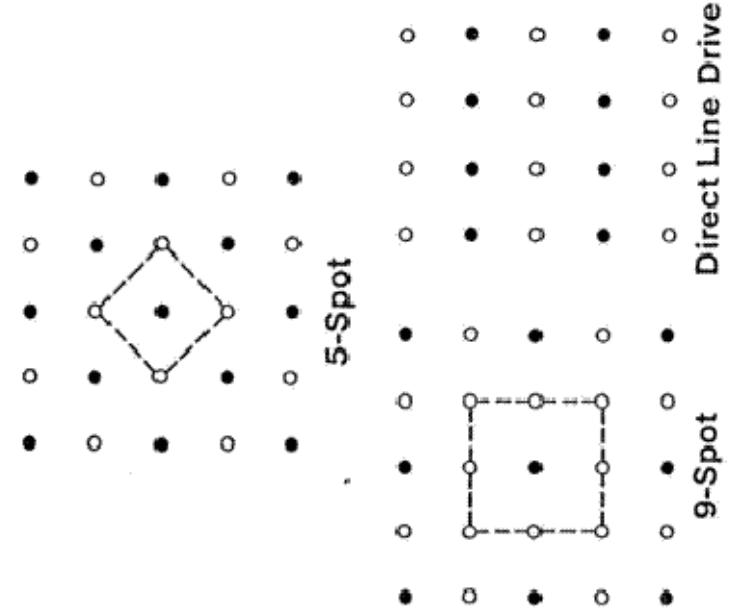
- **Permitting** – Aquifer Protection Permit Application
- **Investigation** – Prefeasibility and Feasibility Studies
  - Data acquisition; data review; site characterization
  - Conceptual and numerical modeling
  - Lab and field tests
- **In-Situ Leach Field Design**
  - In-situ well field design — well pattern, spacing, construction, operation and monitoring
  - Geochemistry: complete analyses and optimization
- **ISL Operation** – Monitoring, Analyses, and Optimization
  - max sweep efficiency and leachability; most effective leach solution composition; minimum cost; minimum environmental impact (short- and long-term)

## Well Patterns



Regular 4-Spot or  
Inverted 7-Spot

Skewed 4-Spot or  
Skewed Inverted  
7-Spot



5-Spot

9-Spot

Direct Line Drive

# Streamlines and Sweep Efficiency

(Pitts & Crawford, 1971)

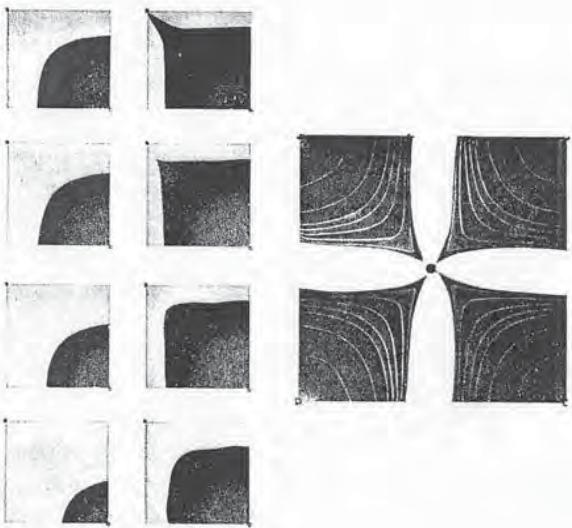
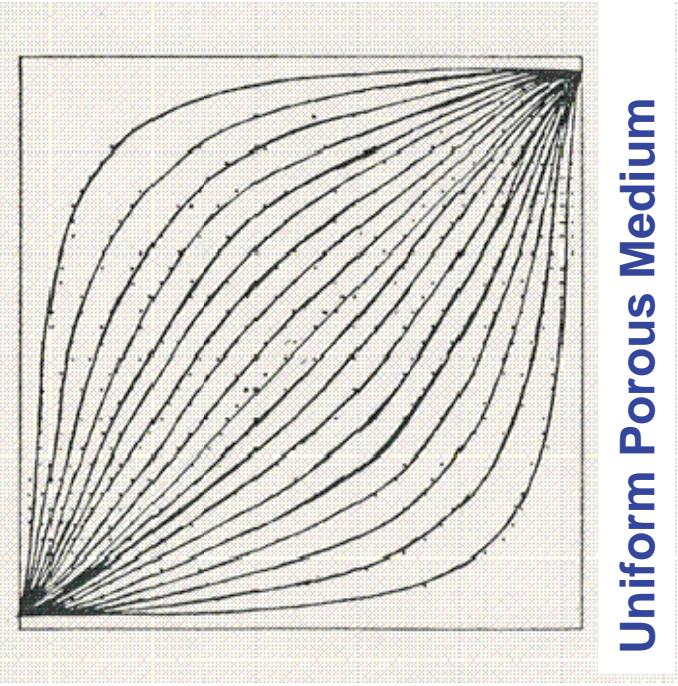


Figure 2. The photographic history of solution movement in a five-spot system.

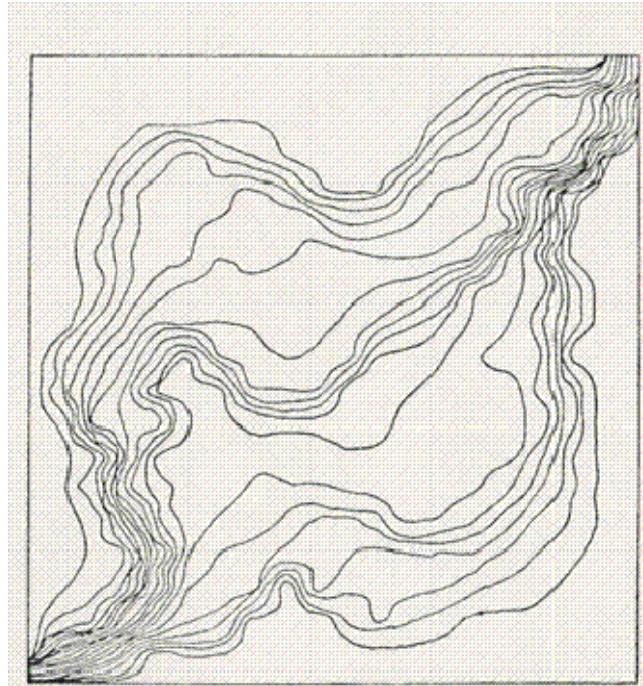
## Five-Spot System

Solution movement from injection wells into a central pumping well in a uniform medium

25%  
sweep  
efficiency

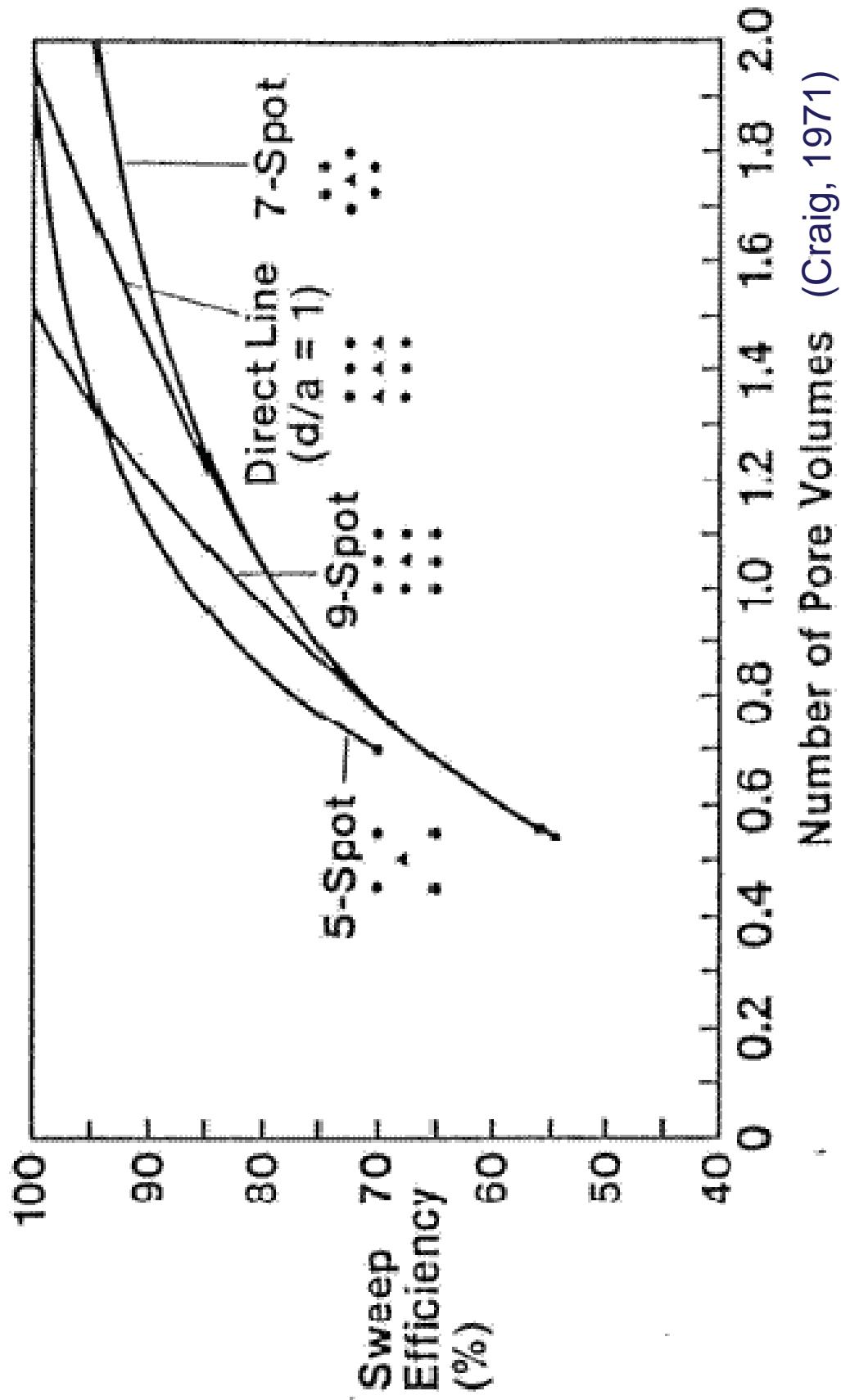


Uniform Porous Medium



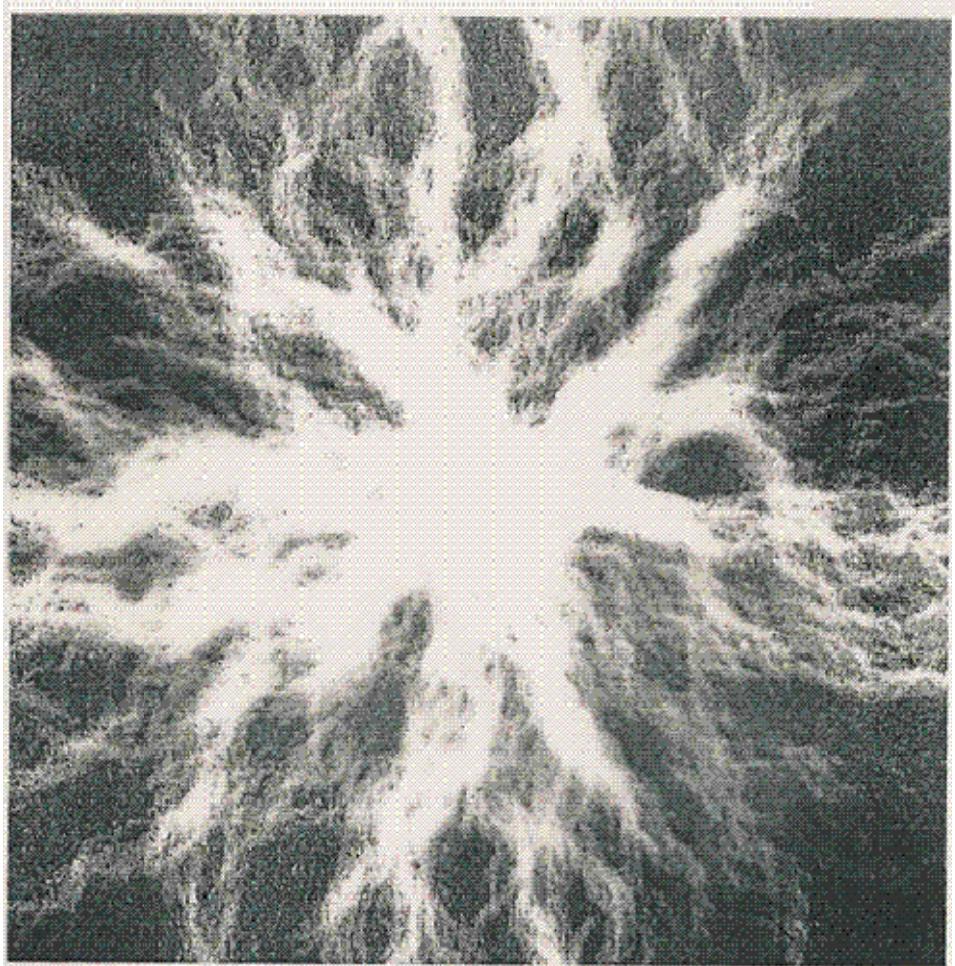
Non-Uniform Porous Medium

# Sweep Efficiency



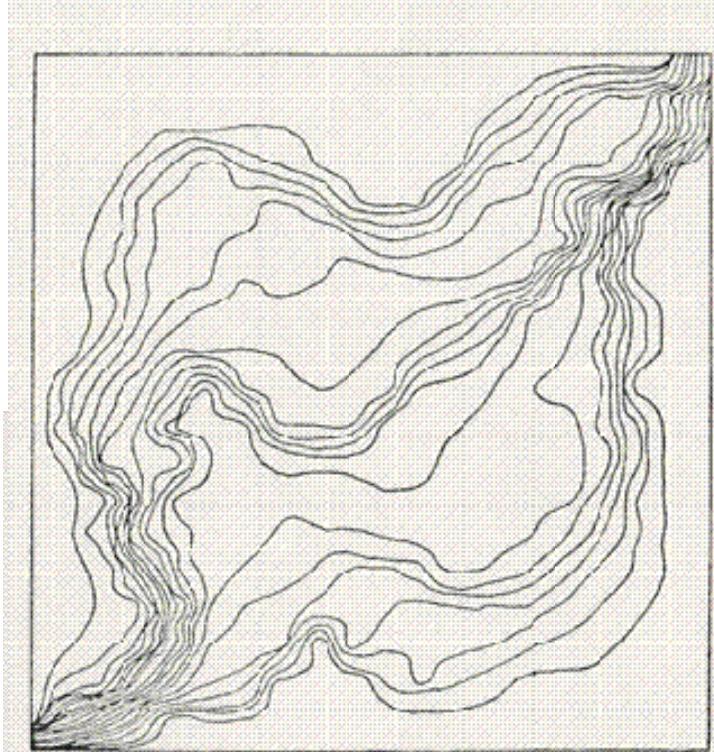
# Effect of Heterogeneity

Desbarats (1992)



Flux intensity into a pumping well in a  
Non-Uniform Porous Medium

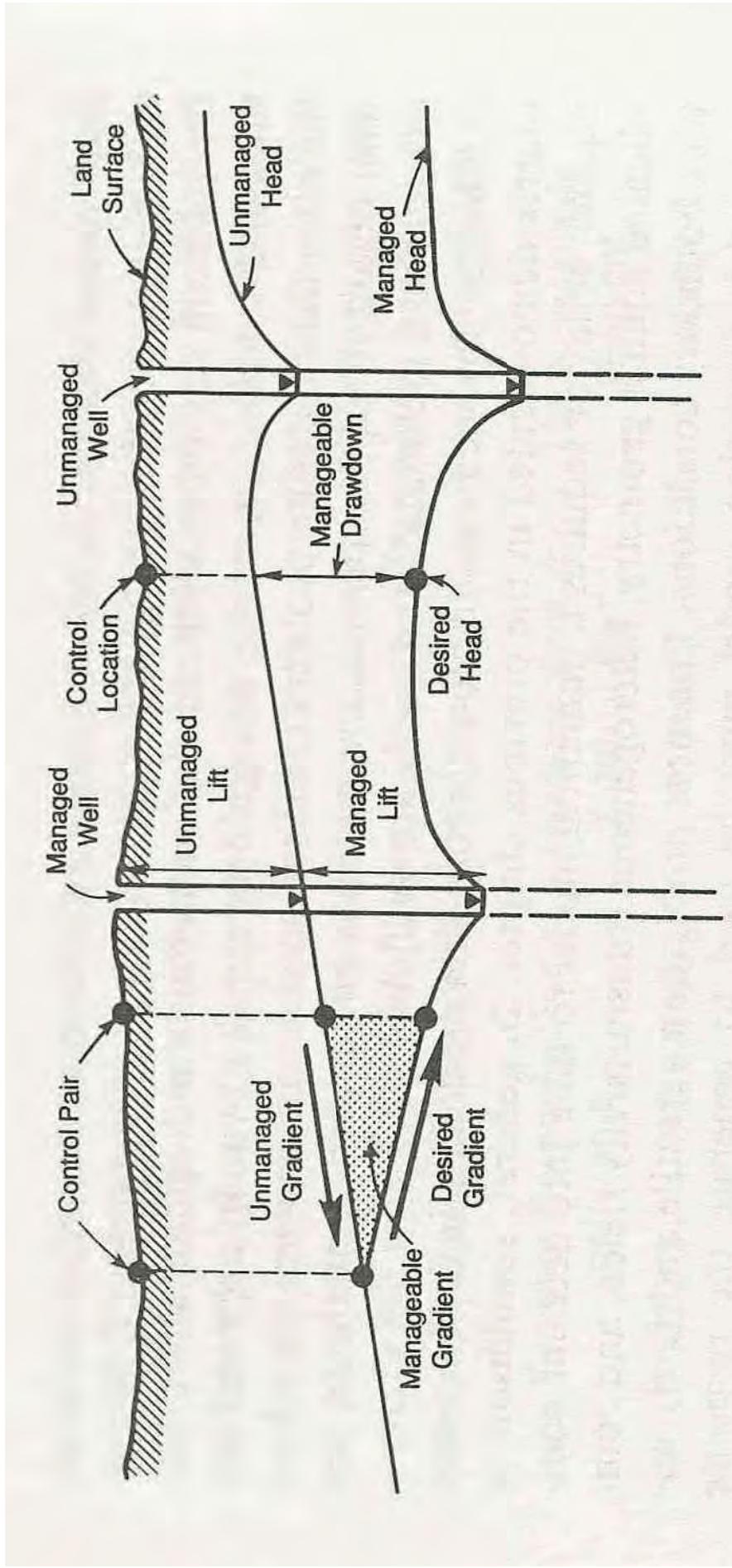
Pitts & Crawford (1971)



Streamlines between an  
injection and a pumping well in  
a Non-Uniform (heterogeneous)  
Porous Medium

# In-Situ Control

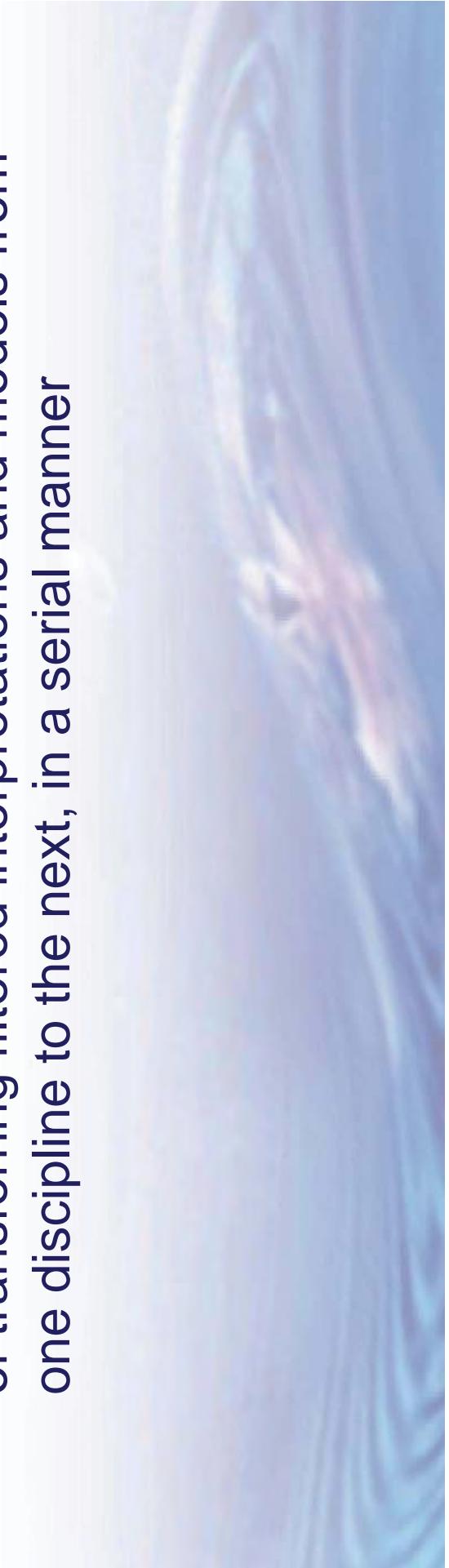
## Hydraulic (Gradient) Control



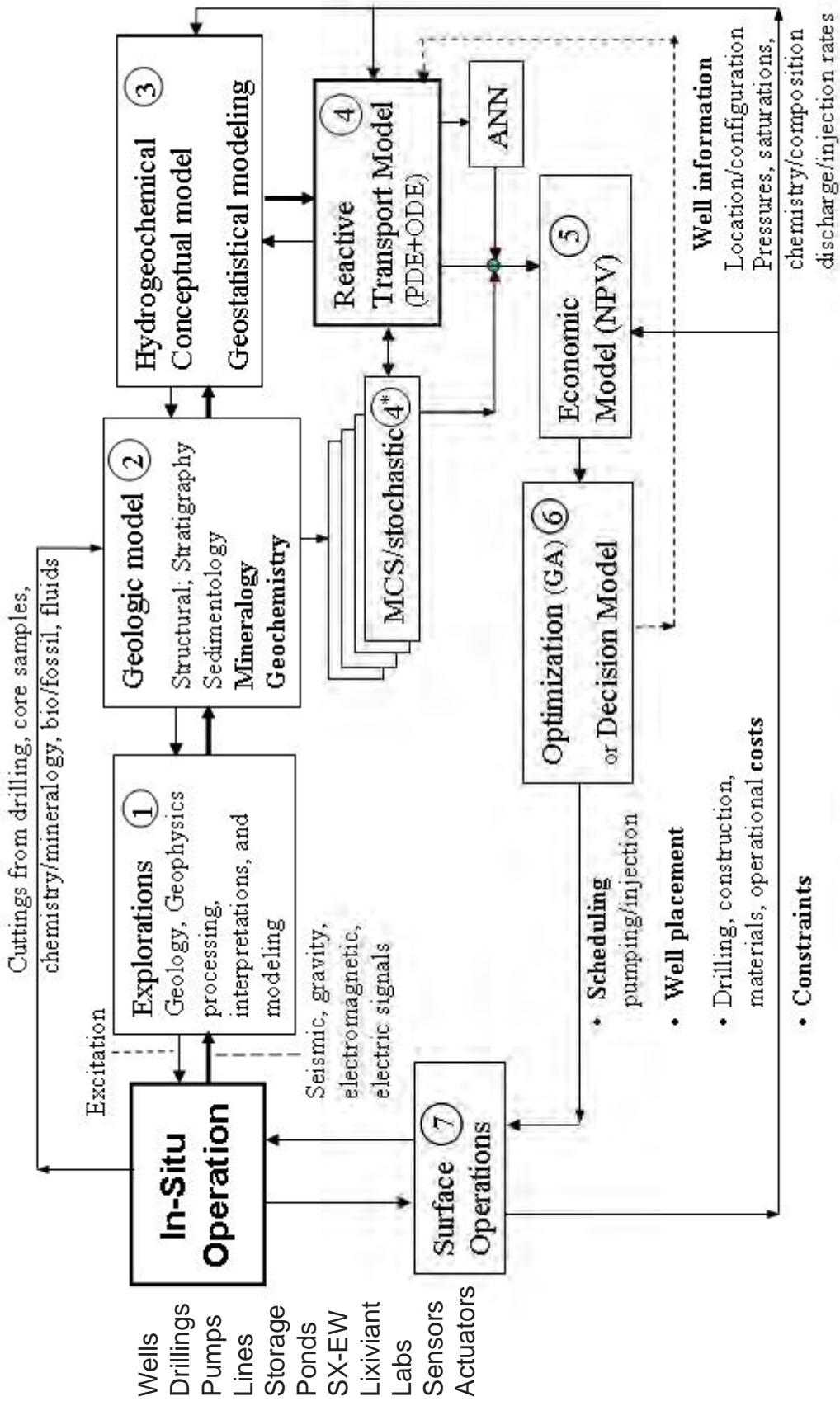
(Gorelick et al., 1993)

# The Management Problem

- ***In-Situ Leaching*** is a complex operation, consisting of various stages and various levels of analyses and optimization
- Borrowed methodologies from the Oil industry consist of transferring filtered interpretations and models from one discipline to the next, in a serial manner

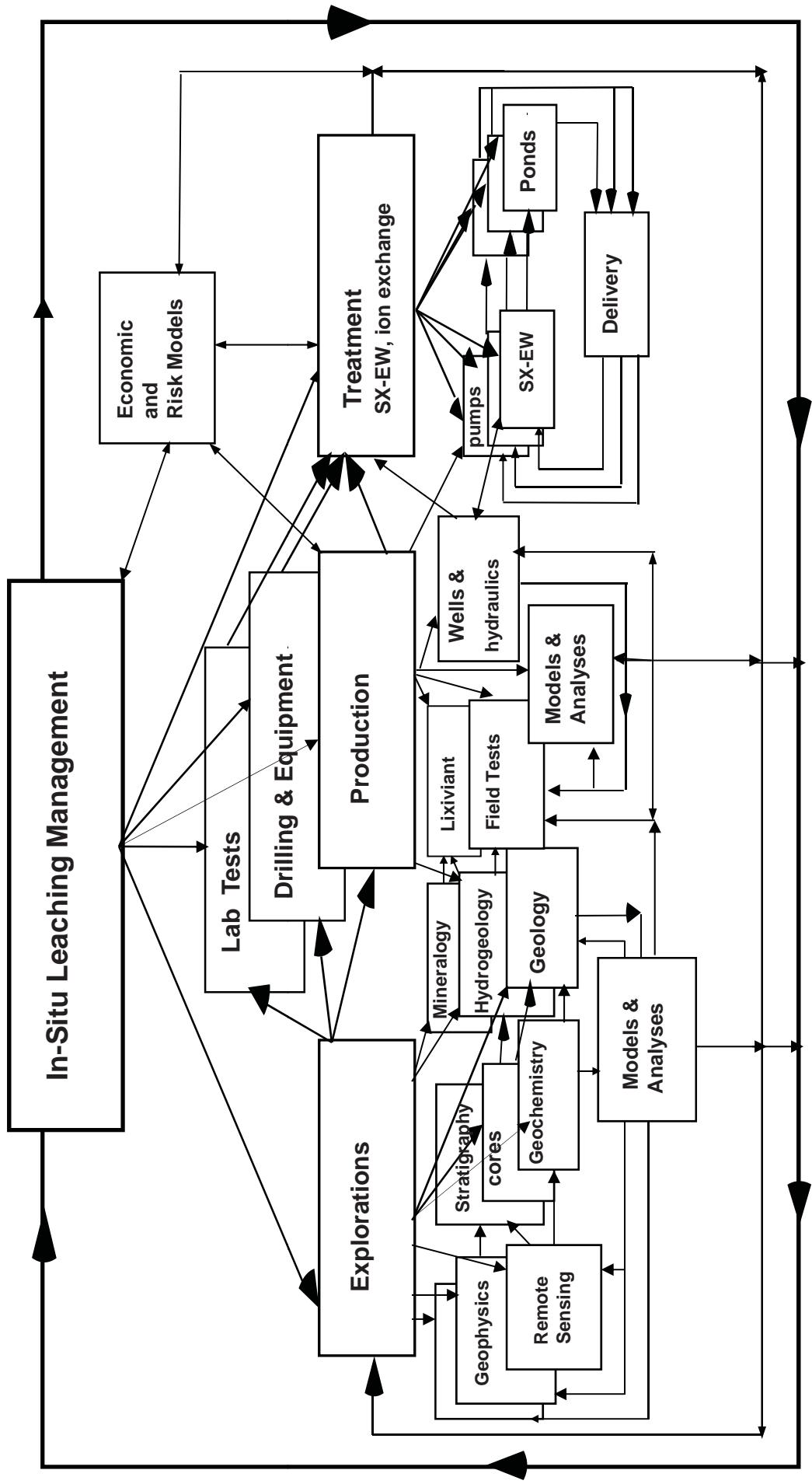


# In-Situ: The Control Loop



(following Orr and Meystel, 2005)

# Hierarchical Control of In-Situ Leaching



(following Orr and Meystel, 2005)

# Conclusions

- *In-Situ Leaching* is a complex multi-disciplinary operation
- A high level of expertise in all disciplines – Geology, Hydrogeology, and Metallurgy
- Understanding heterogeneity on all scales and dealing with inevitable uncertainty
  - Understanding and dealing with sensitivities to hydraulic and geochemical parameters
- Dynamic, multilevel management, with continual data assimilation, integration, quantification, modeling, and optimization under uncertainty

**WATER**  
MANAGEMENT  
CONSULTANTS

**Thank You!**

